Evaluation of the Wind Direction Uncertainty And Its Impact on Wake Modelling at the Horns Rev Offshore Wind Farm

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Aero-elastic Section, Wind Energy Department, DTU, Risø

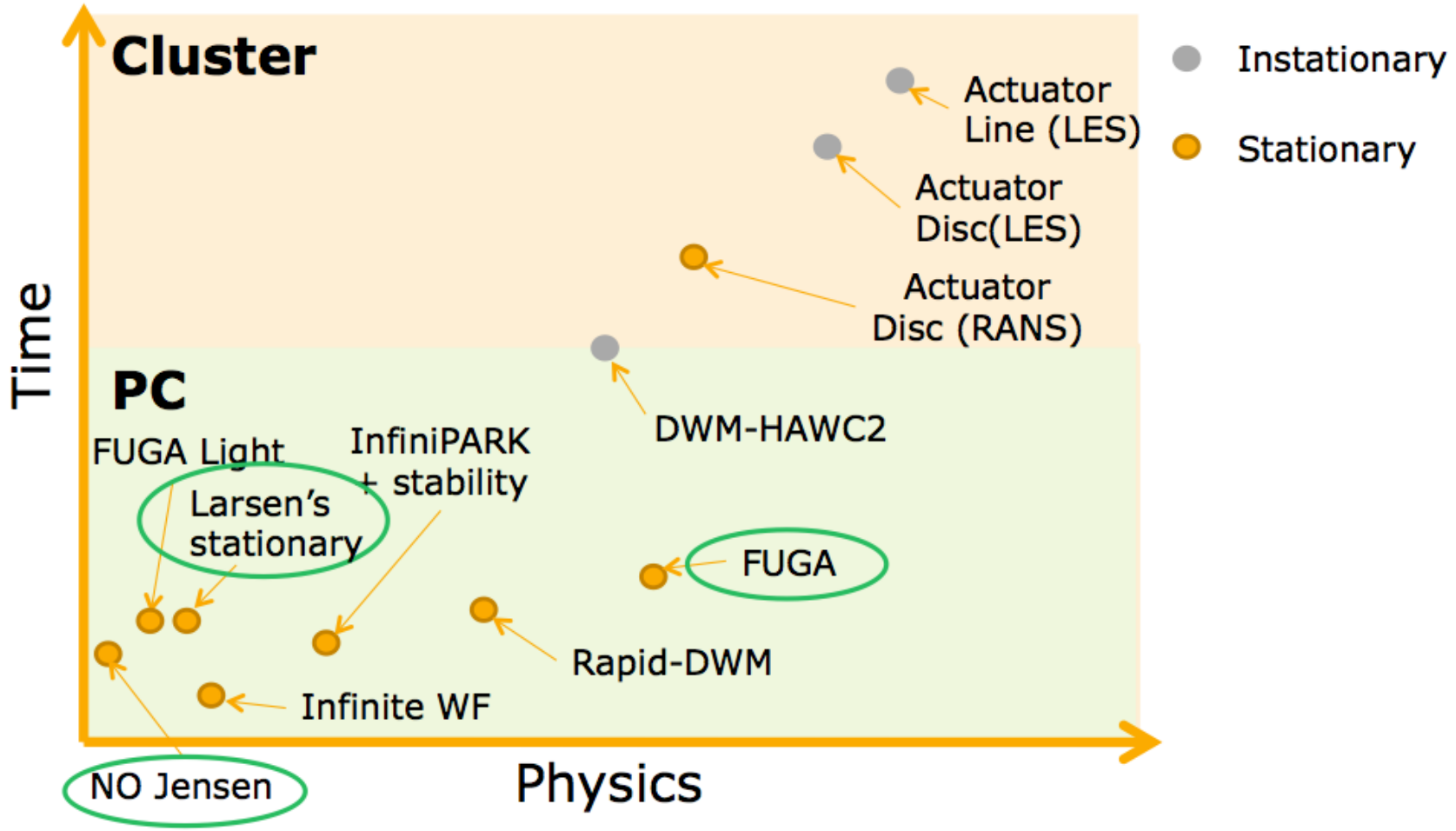
Windpower Monthly's Wind Farm Data Management and Analysis forum
23-25 September

DTU Wind Energy
Aero-Elastic Design Section - Risø

Outline

1. Why Uncertainty Matters?
   - Introduction
   - Method: Modelling the wind direction uncertainty
   - Results
2. Adding Value to Wind Farm Data
   - Machine Learning and Physical Modelling
   - The FUSED-Wind project
   - A Future Business Concept
3. Conclusion and Future Works

Overview of DTU's Wind Farm Flow Models



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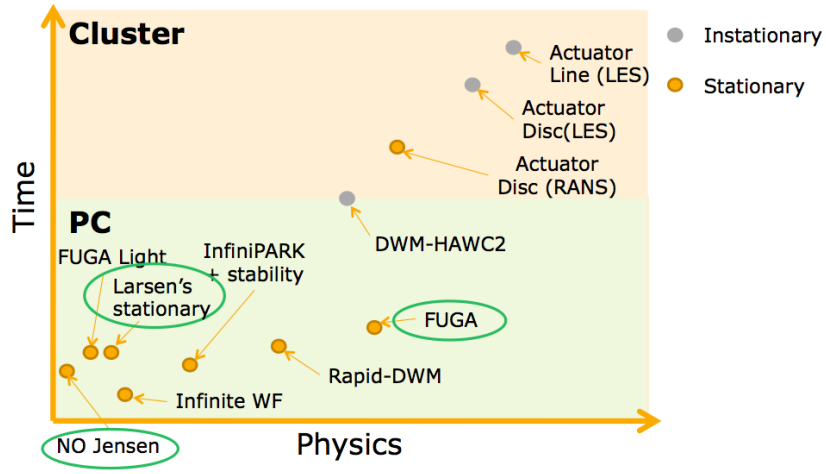
What Are Those Models used for?

- Estimating Annual Energy Production
- Wind Farm Optimization



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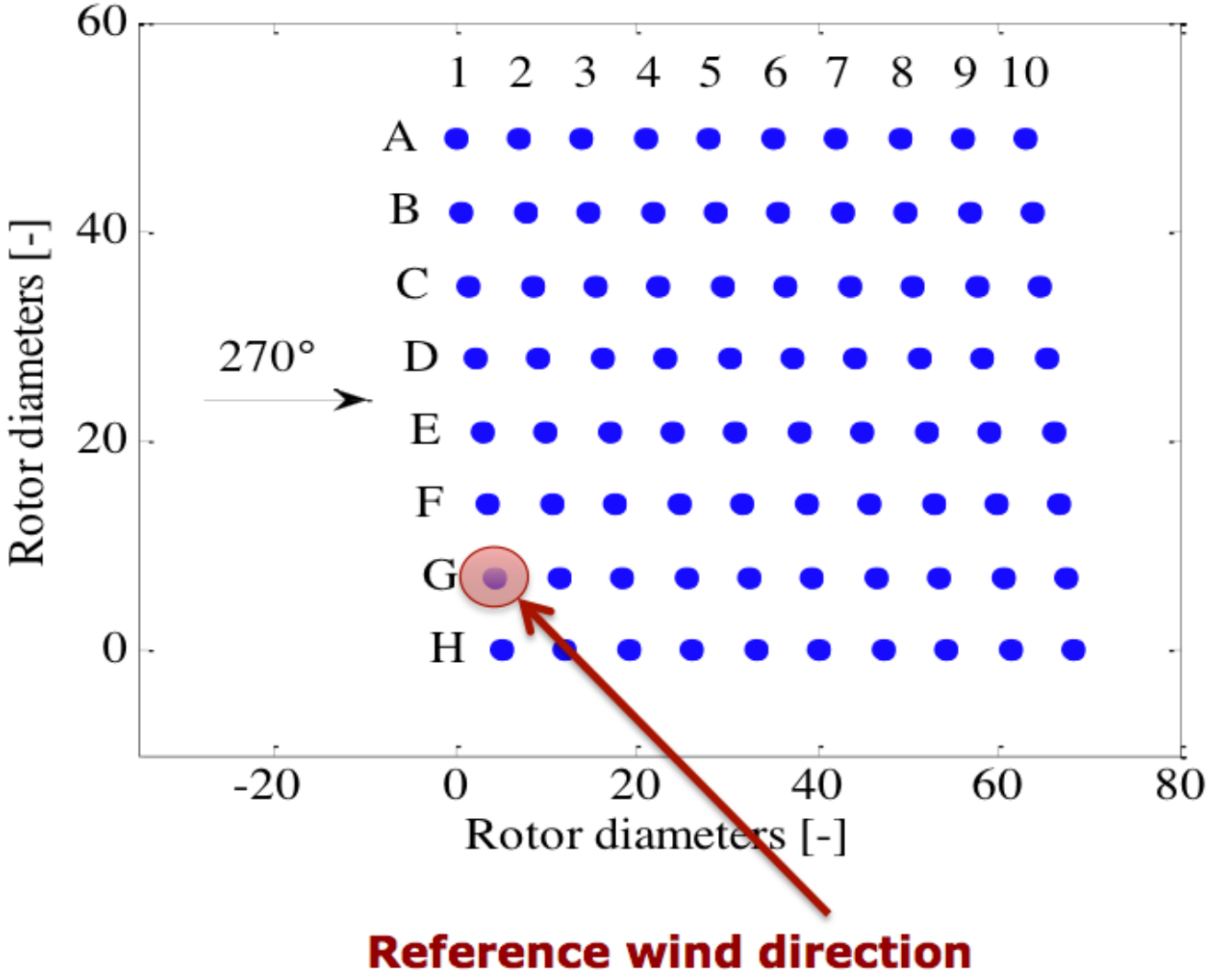
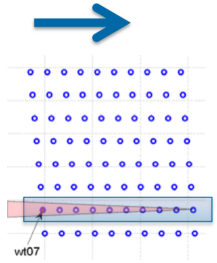
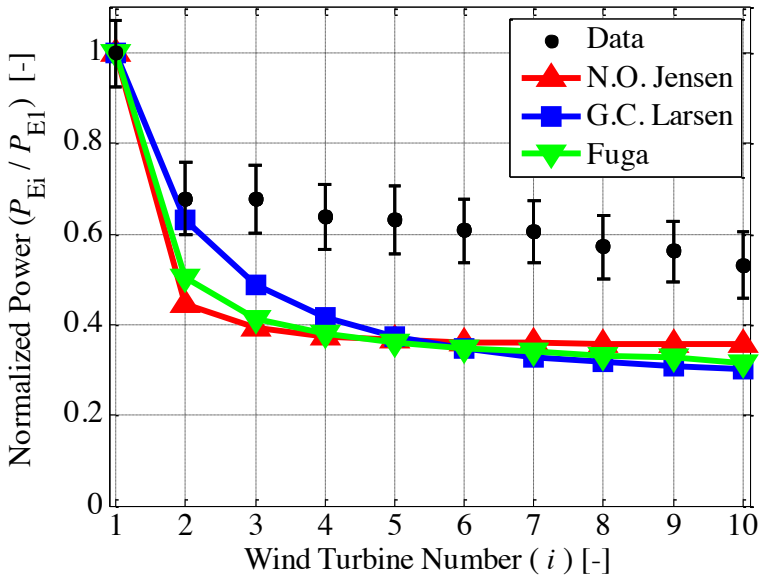
The Horns Rev test case - Western winds



Results of the Wake Model Benchmarking: Confusion!

270° ± 2.5°





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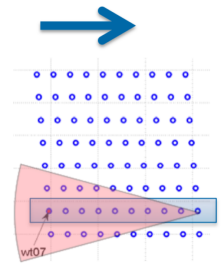
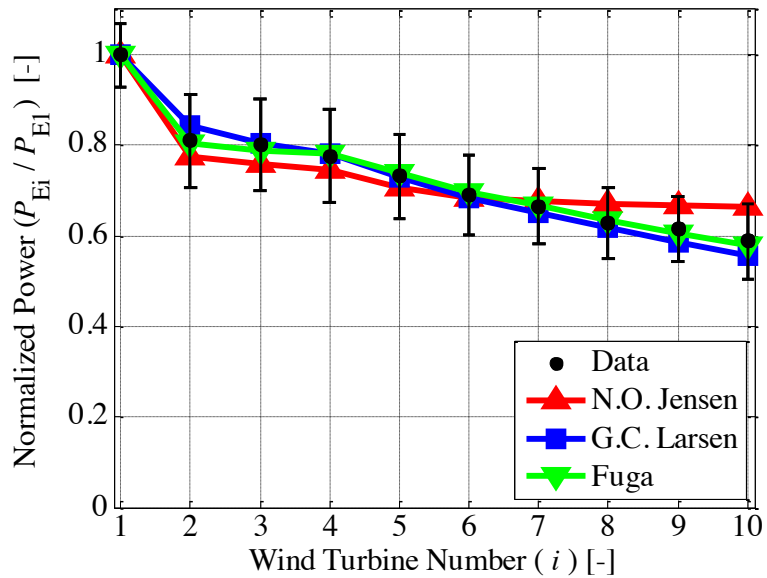
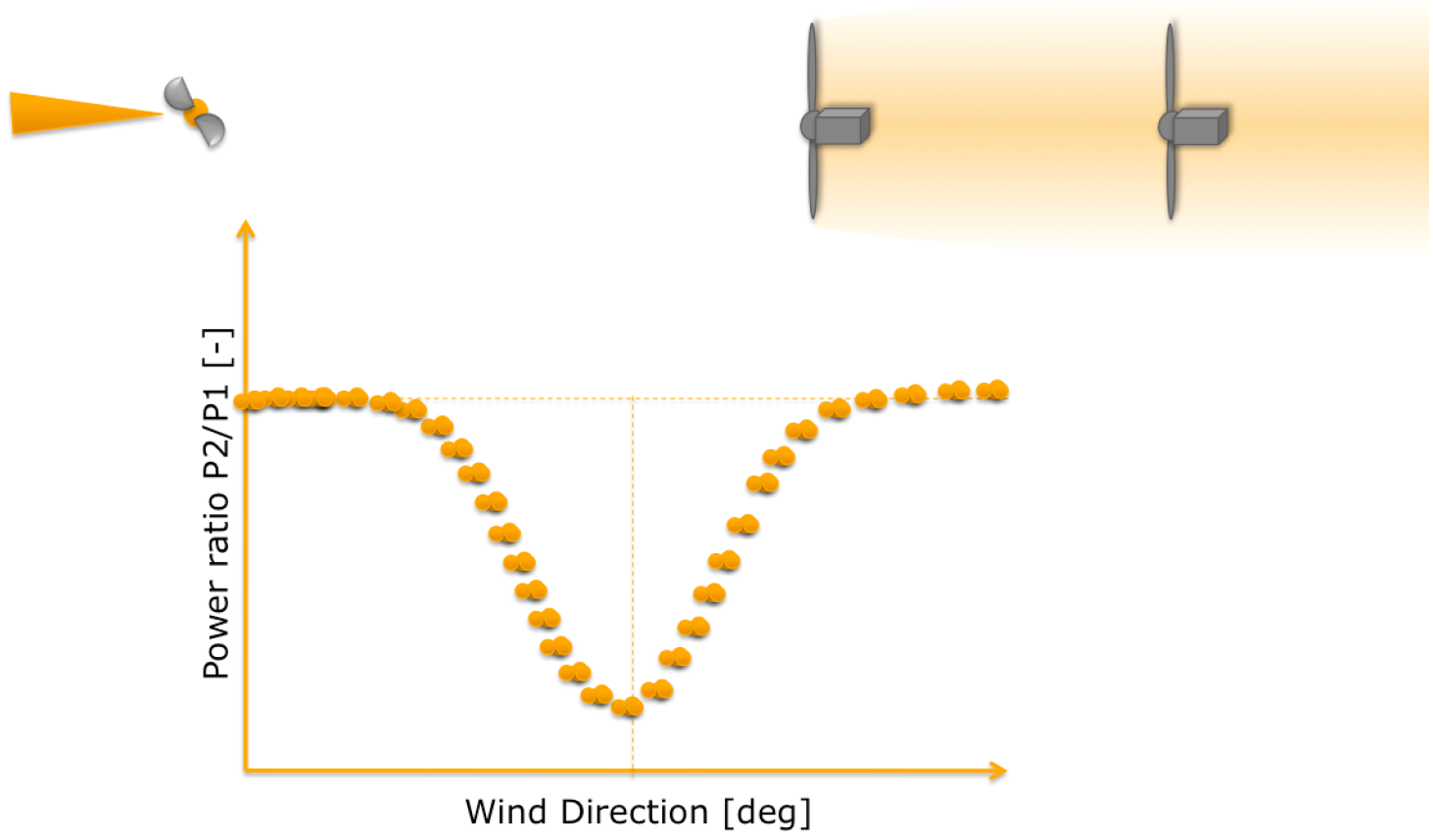




The effect of wind direction uncertainty on wind farm wake measurement



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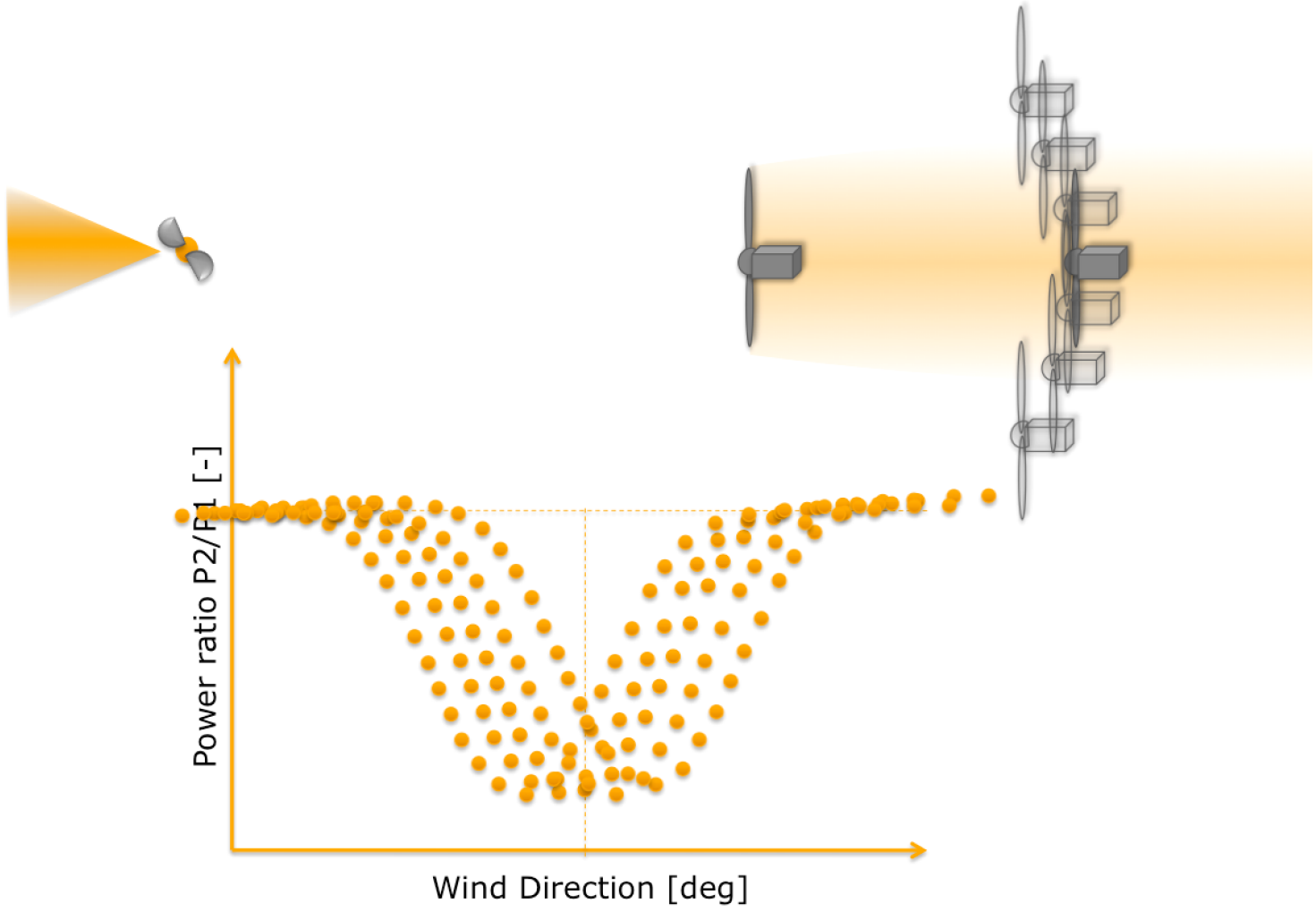

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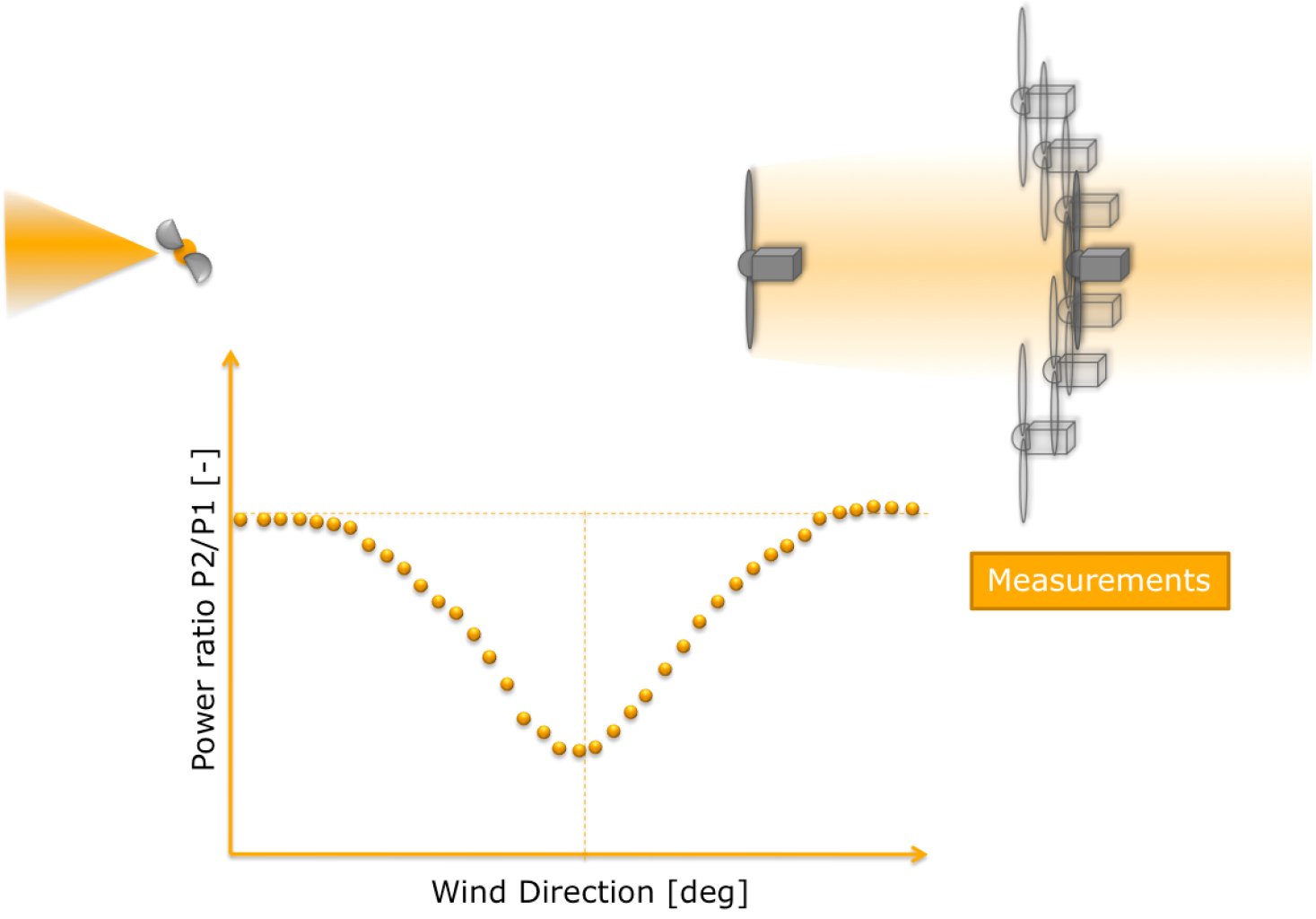

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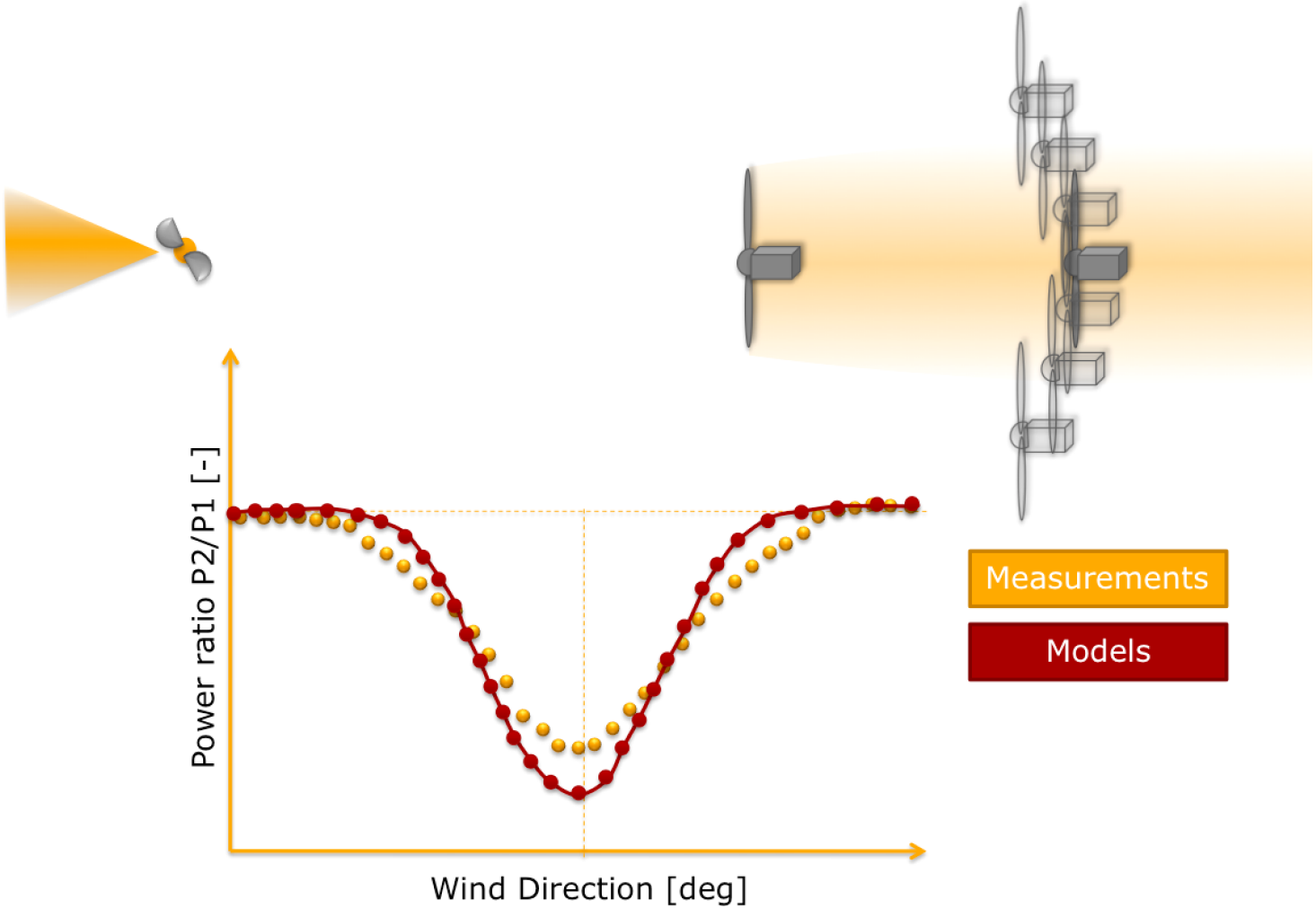

Sources of wind direction uncertainty

Random/temporal bias from the measurement device

- Yaw misalignment (when yaw sensor is used to measure direction)
- Time drift of the calibration
- Failures

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- Small scale turbulence (sub 10-minute)
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- Large scale turbulence (i.e. wind directional trends, over 10-minute)

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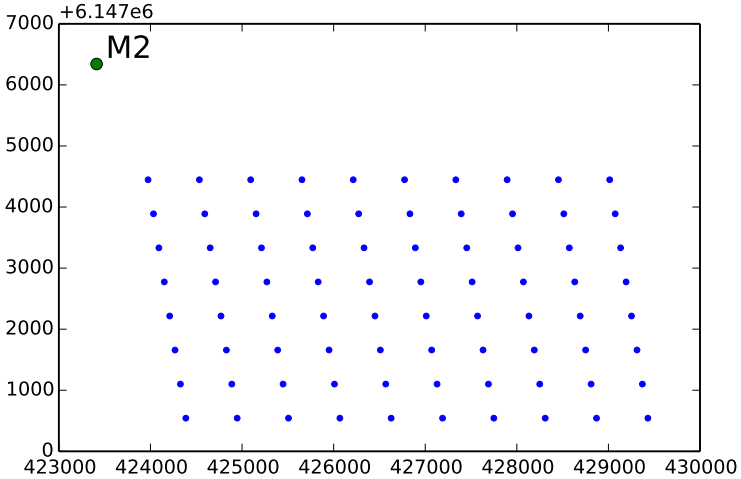
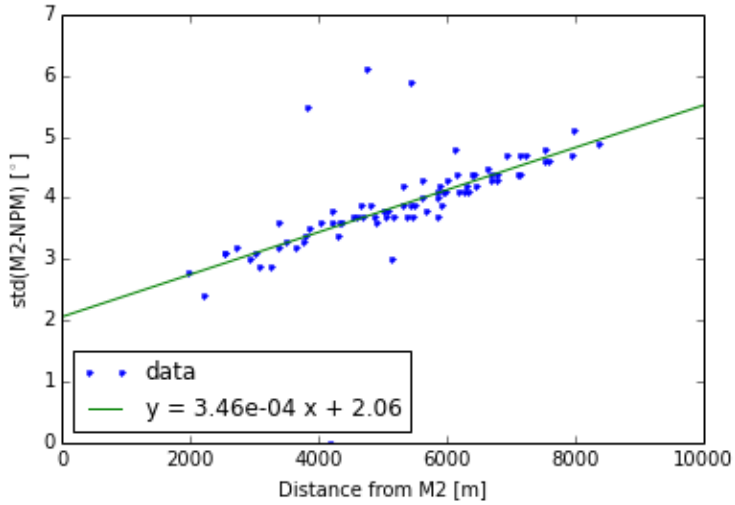
Wind direction coherence

- Spatial variability of the wind direction
- Different time-control volume averaging

Spatial decorrelation of wind direction

The wind direction correlation between M2 and the wind turbines decreases linearly with the distance





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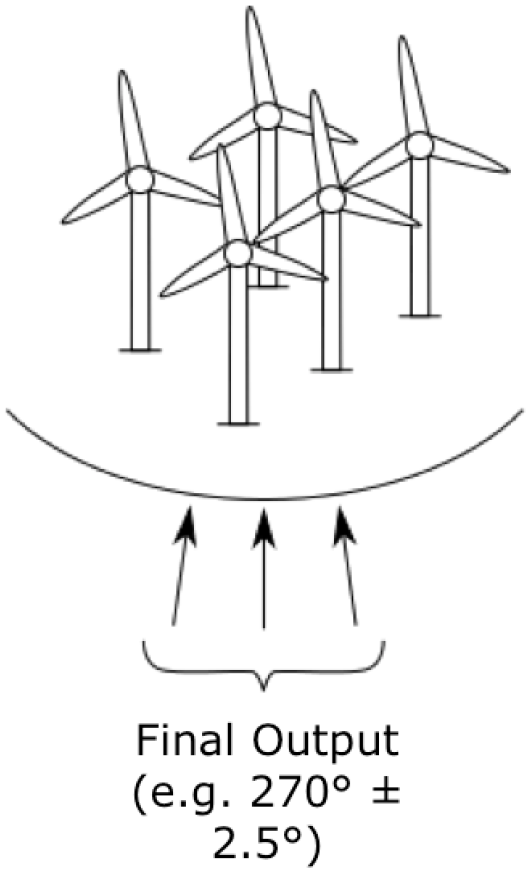
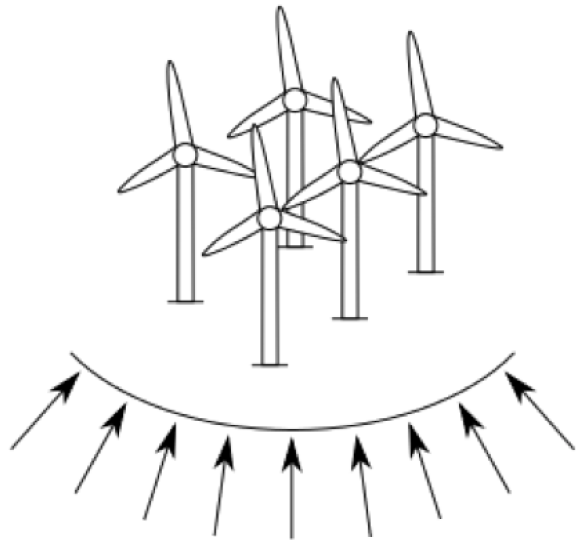
The "traditional" method

- Step 1: Run simulations with fixed and homogeneous wind direction covering the desired wind direction sector
- Step 2: Apply a linear average to reproduce the data post-processing



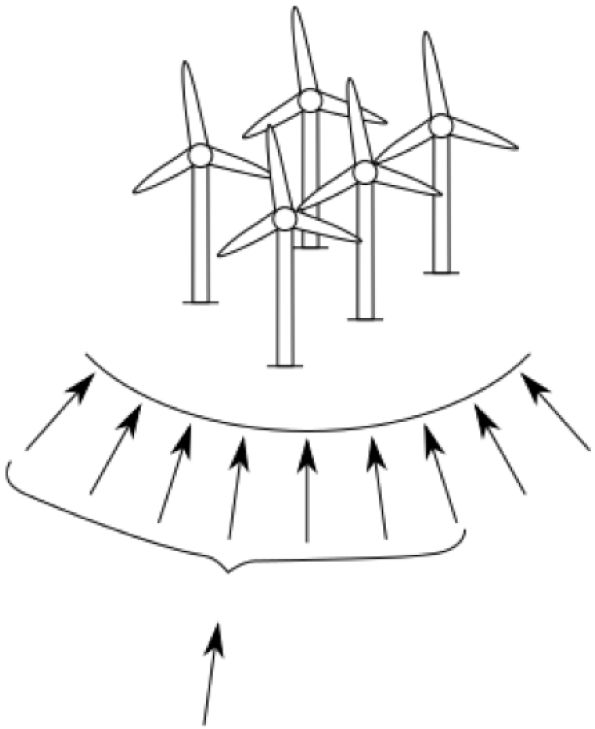
The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction



The proposed method

- Step 1: Run simulations with fixed and homogeneous wind direction
- Step 2: Apply a weighted average based on the probability function of a normal distribution on the interval $\pm 3\sigma$



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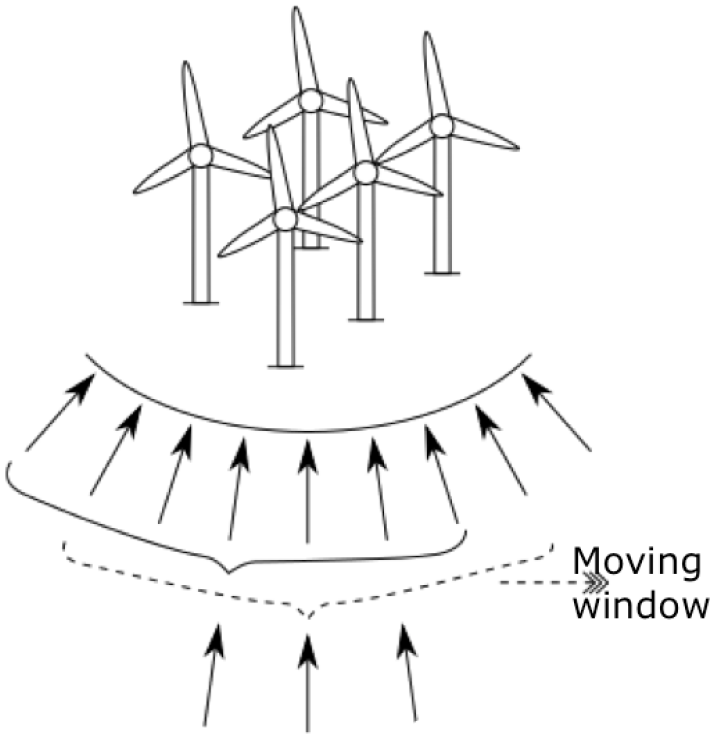

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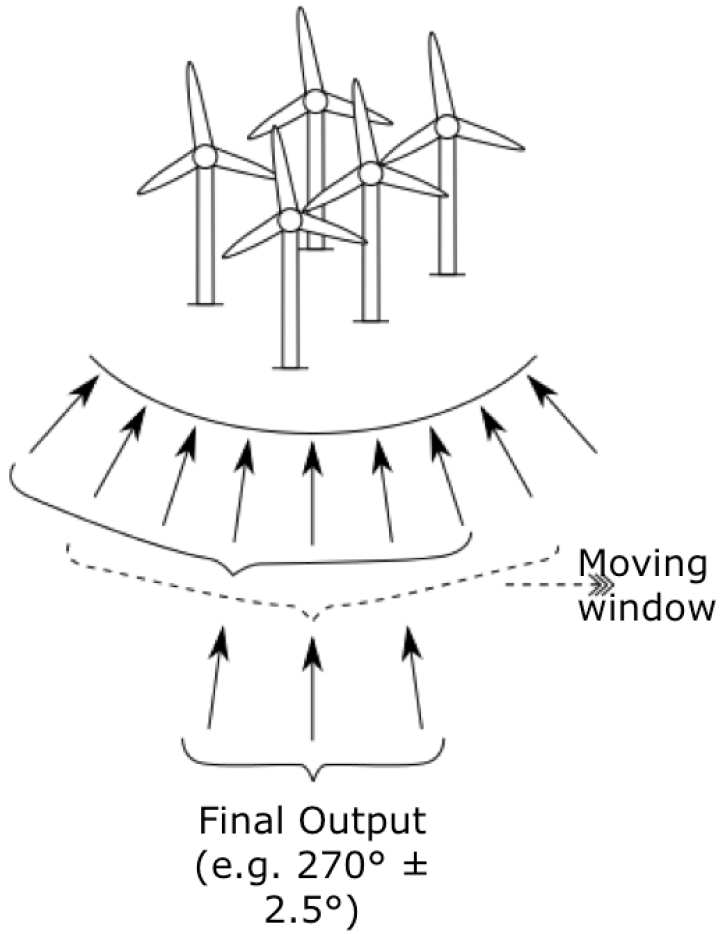
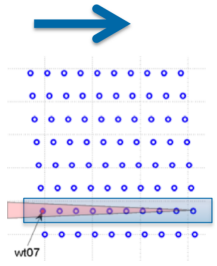


All the rows, using a row-specific wind direction uncertainty

270° ± 2.5°



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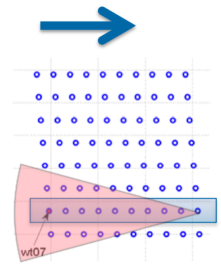

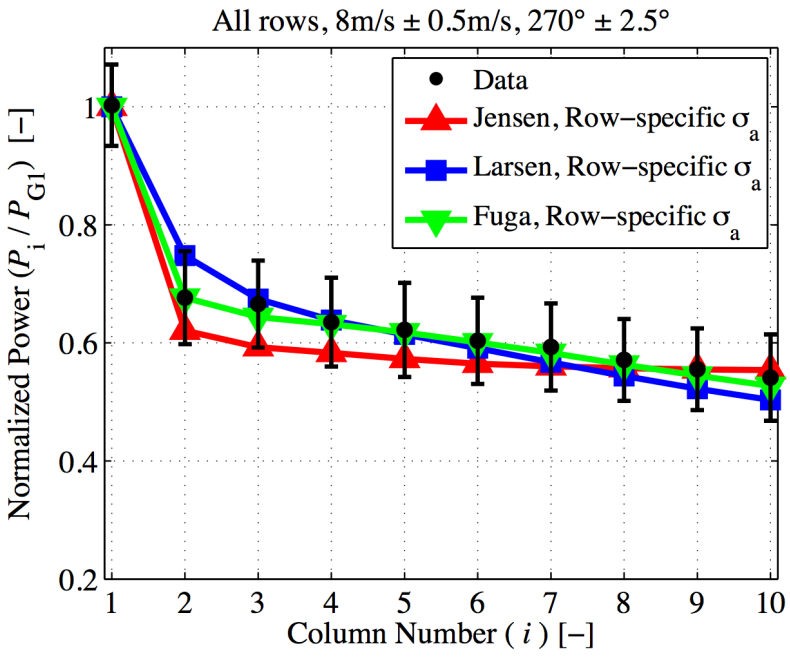

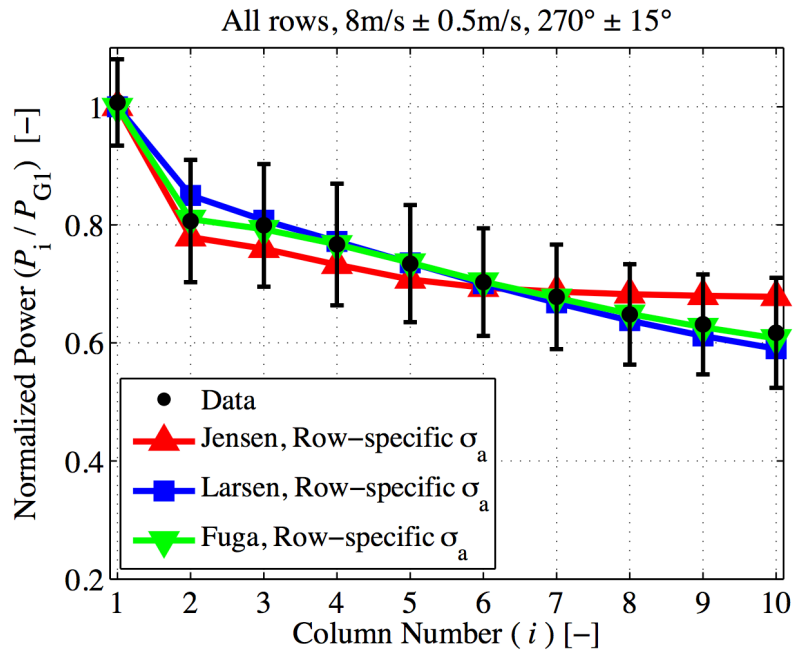

Result for the whole wind farm in $\theta = 270°$

	270 ± 2.5°	270 ± 15°
Power Data	64.7%	73.9%
NOJ, Baseline	-20.9%	+0.4%
GCL, Baseline	-20.9%	-0.1%
Fuga, Baseline	-21.7%	-0.3%

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NOJ, σ=3.5°	-11.6%	+0.0%
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NOJ, row-specific	-3.1%	+0.1%
GCL, row-specific	-0.7%	-0.2%
Fuga, row-specific	-0.8%	-0.2%

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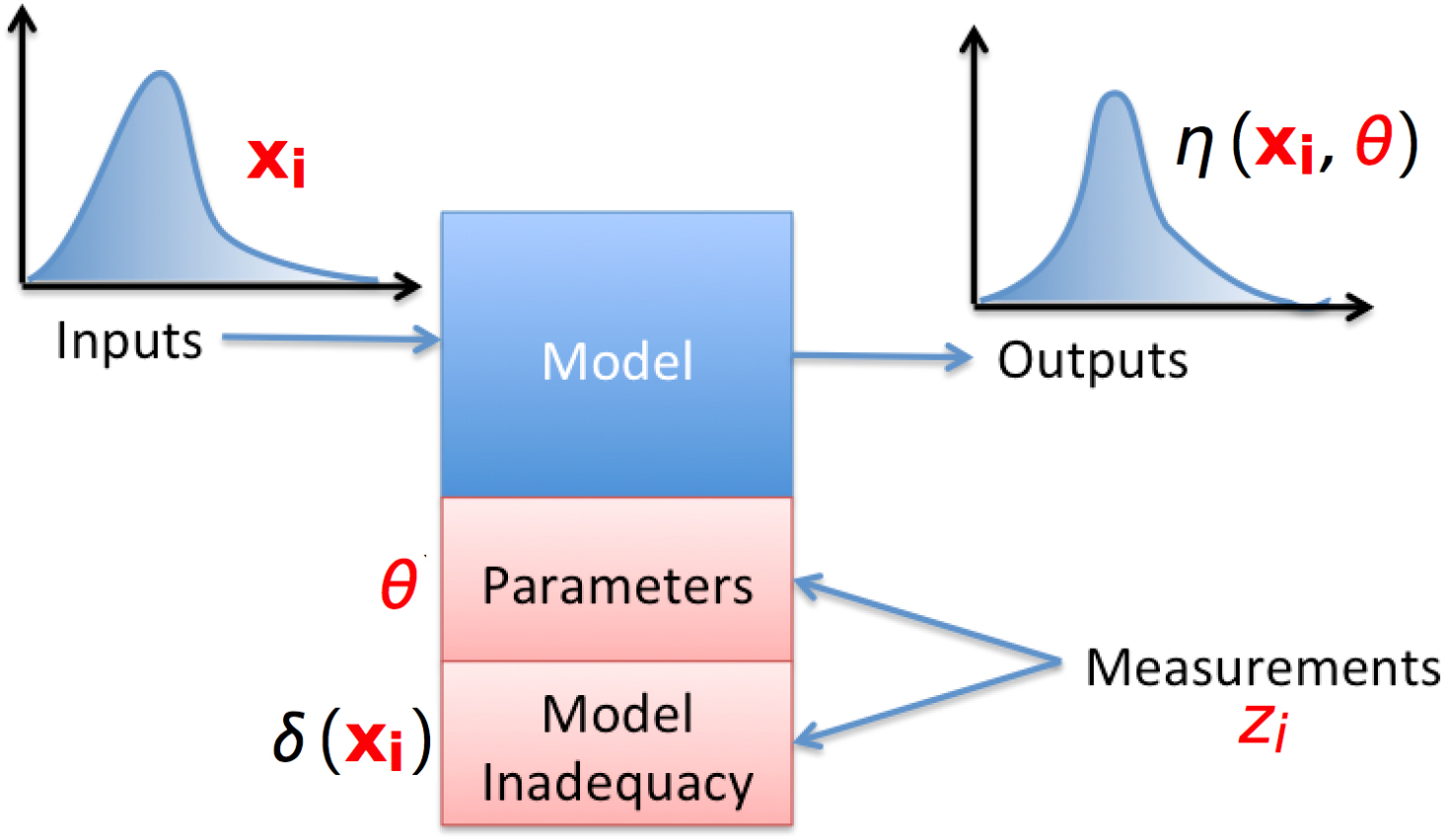
From Deterministic to Stochastic

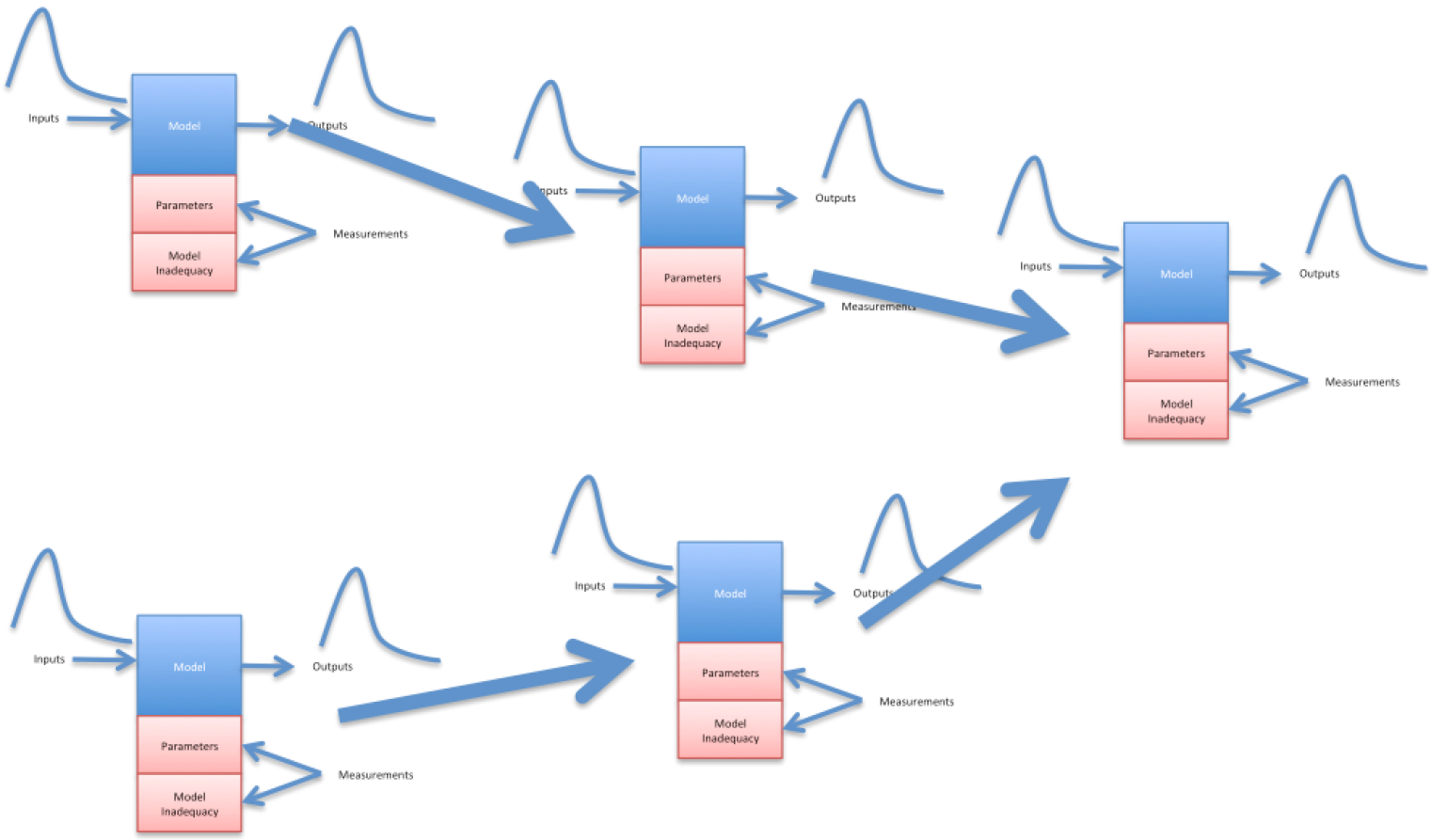
$$\zeta_i(\mathbf{x_i}) = \eta(\mathbf{x_i}) \tag{1}$$

From Deterministic to Stochastic

$$z_i = \zeta_i(\mathbf{x_i}) + \varepsilon_i = \eta(\mathbf{x_i}, \theta) + \delta(\mathbf{x_i}) + \varepsilon_i \quad (2)$$



System Engineering



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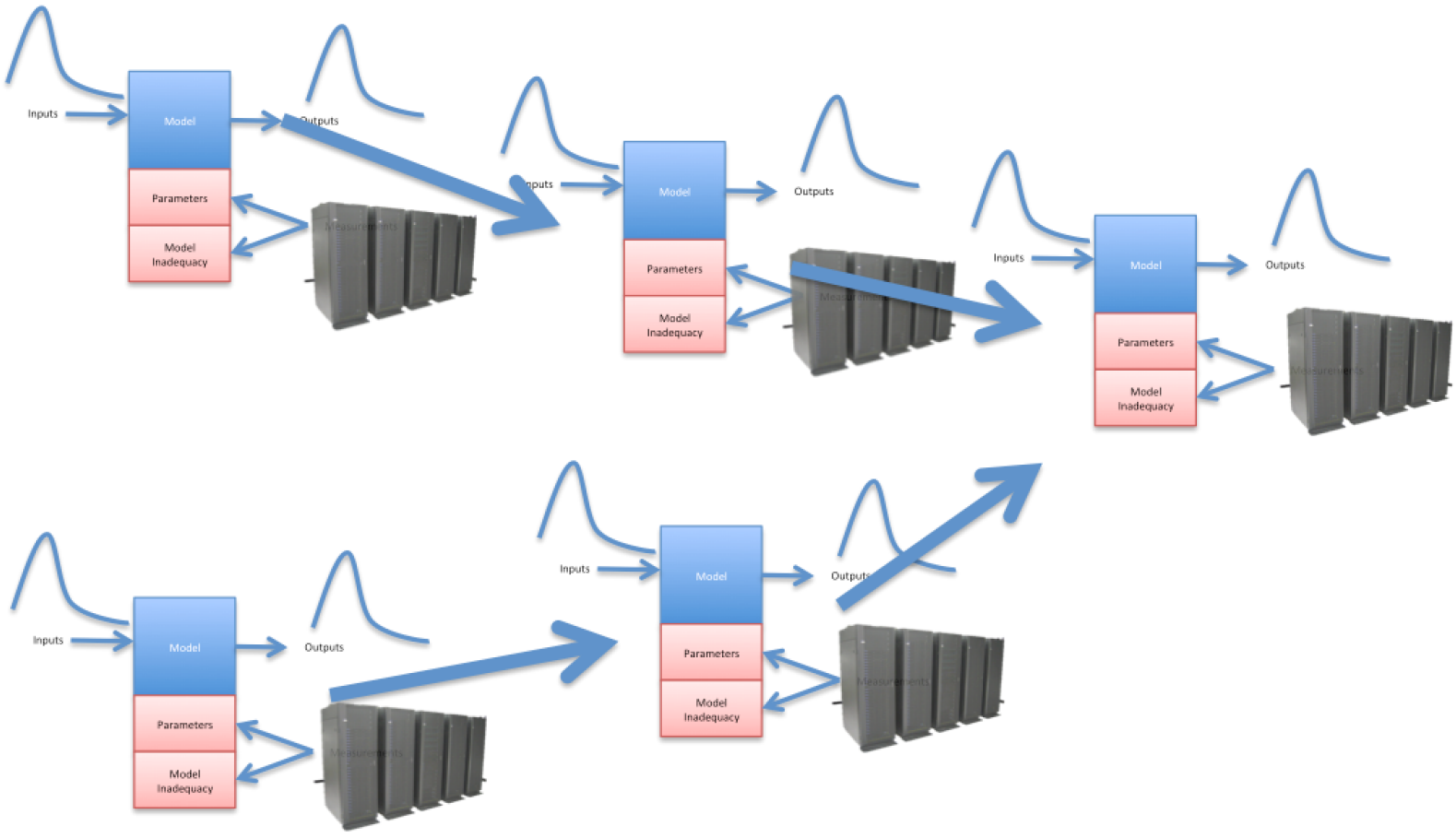
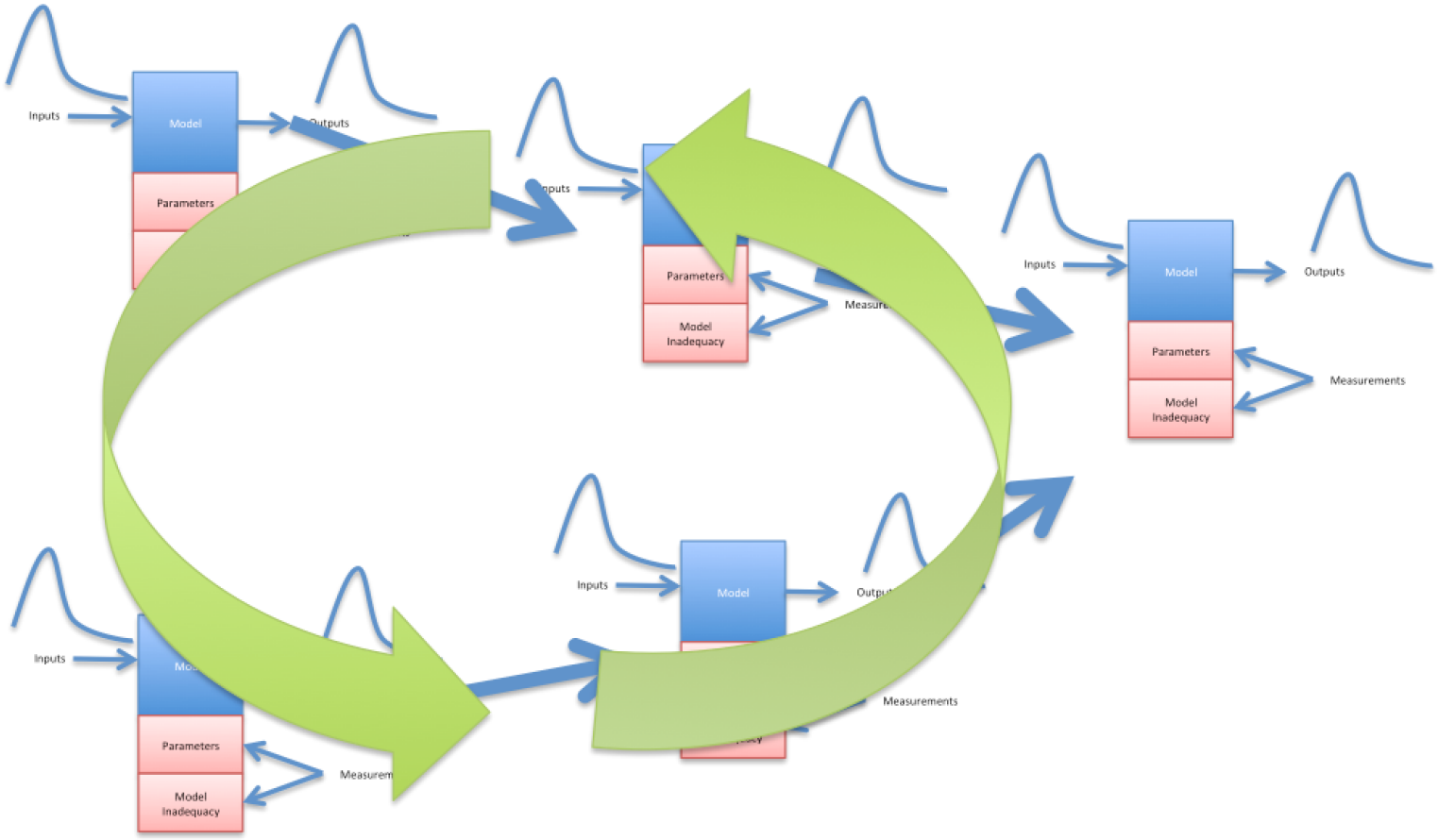
System Engineering - Big Data



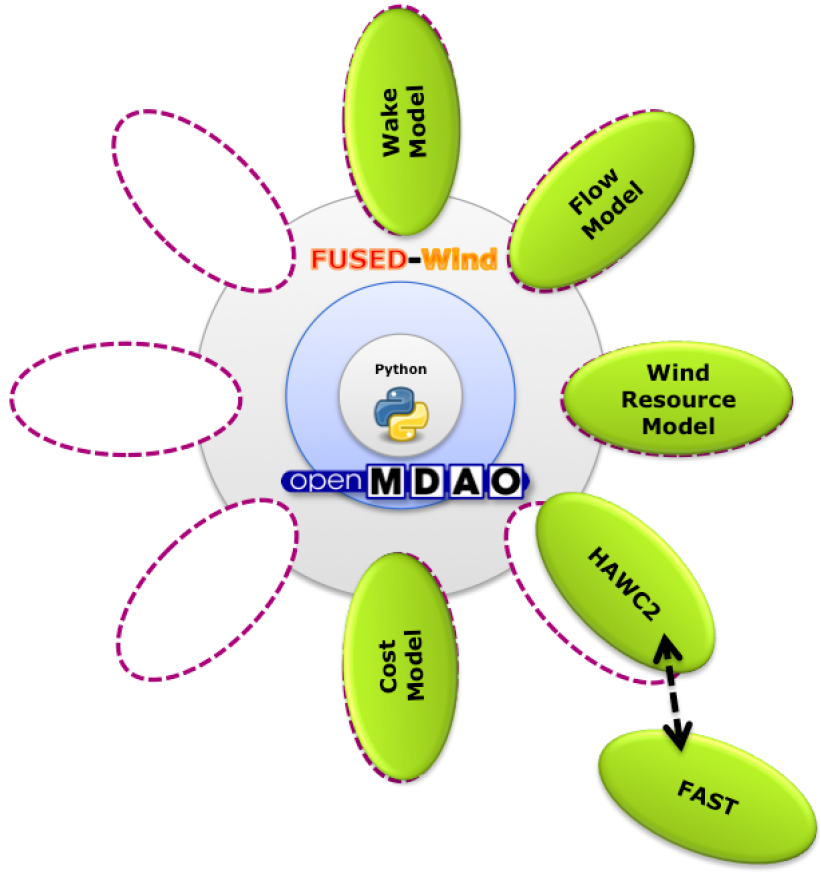
System Engineering - Augmented Intelligence



The FUSED-Wind project

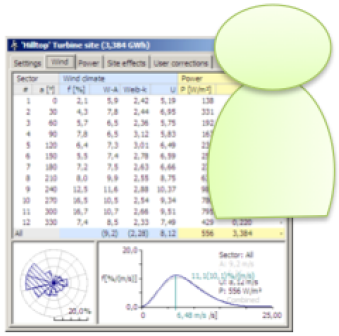
Connecting All Wind Energy Models in a Worflow

- Collaborative effort between DTU and NREL to create a **F**ramework for **U**nified **S**ystem **E**ngineering and **D**esigned of **Wind** energy plants.
- Based on OpenMDAO, a python based Open source framework for **M**ulti-**D**isciplinary **A**nalysis and **O**ptimization.
- FUSED-Wind will offer built in capabilities for Uncertainty Quantification, Machine Learning and Optimization



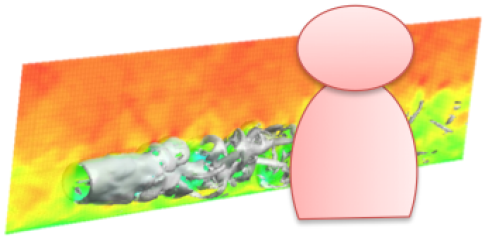
A Future Business Concept

Concept



WAsP
SmartWake client

Cloud Cluster
SmartWake Server



Wake Modelers

Wind farm SCADA owners

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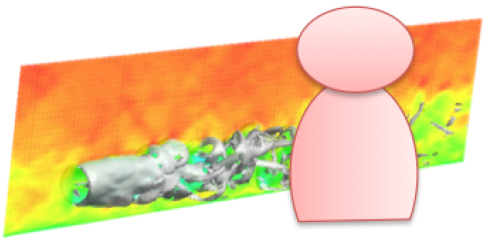

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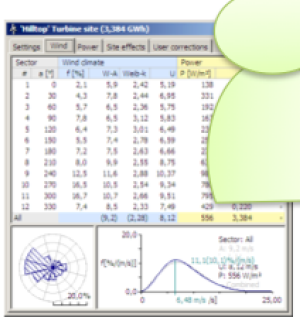
A Future Business Concept

I want to plan a wind farm

Concept



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Cluster
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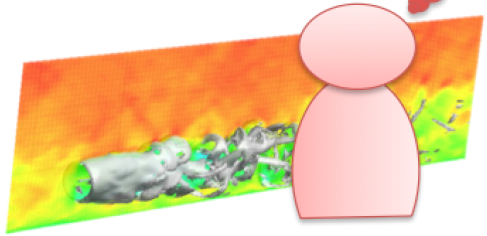
I want my wake model to be useful



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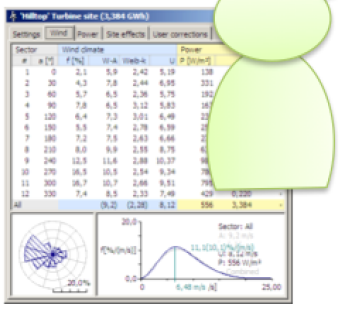

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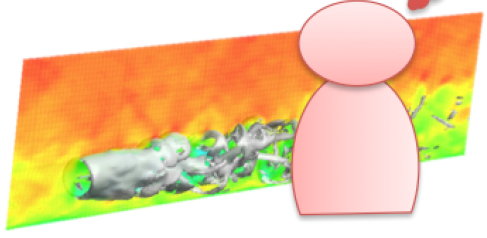


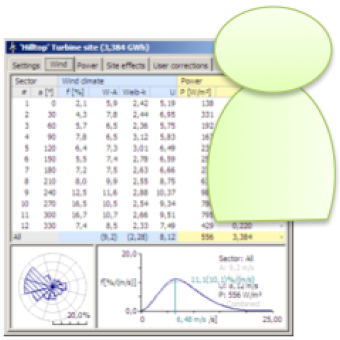
Wake Modelers

I want add value my wind farm SCADA data

Wind farm SCADA owners

A Future Business Concept

Concept



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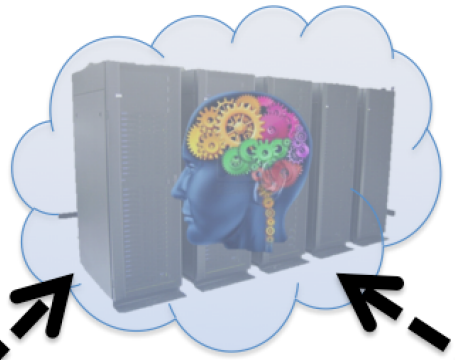

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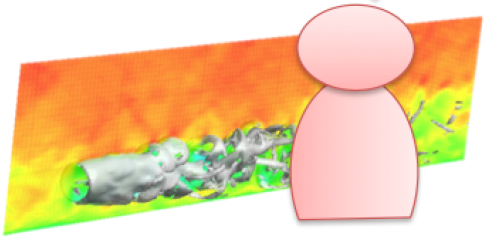

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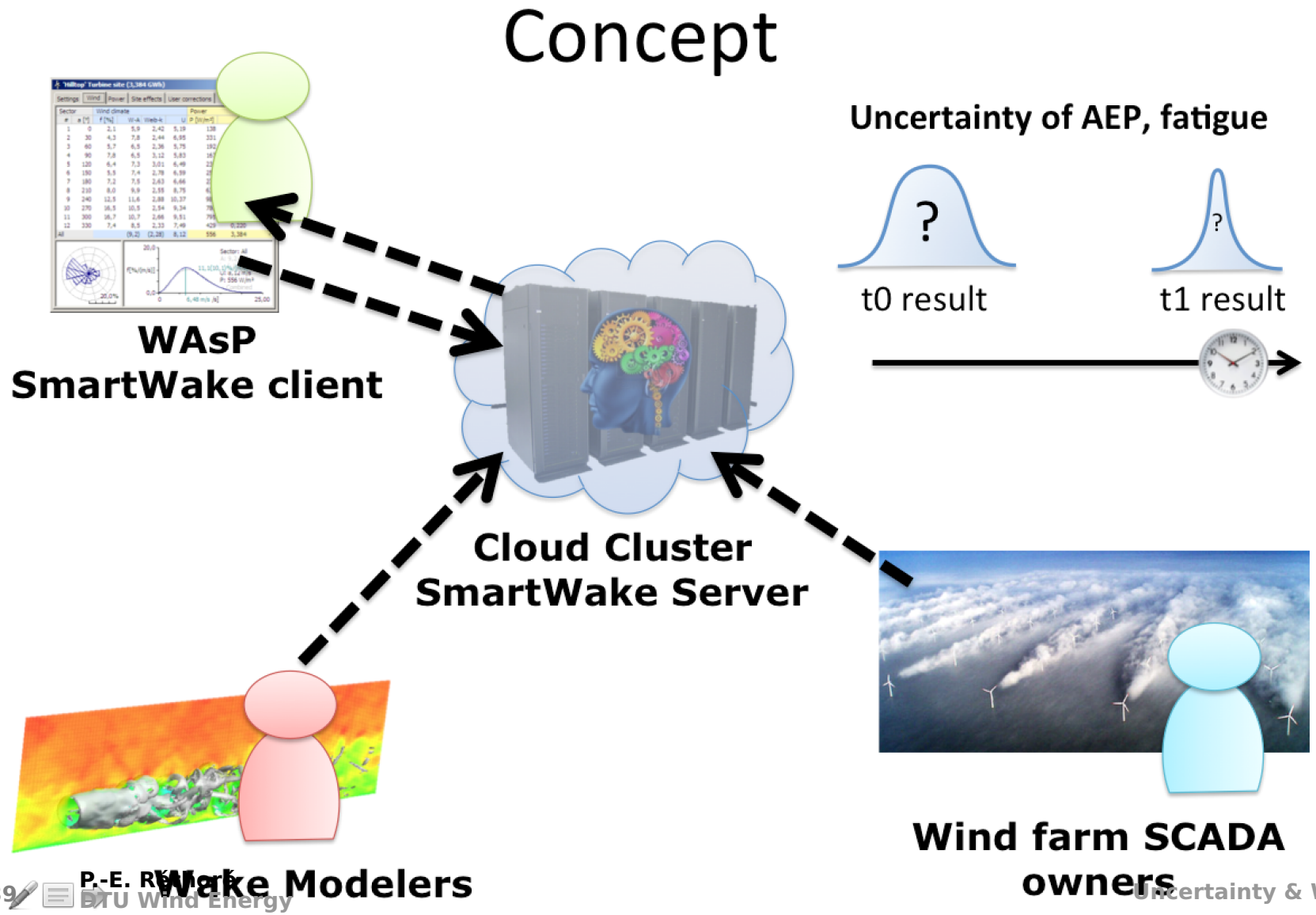

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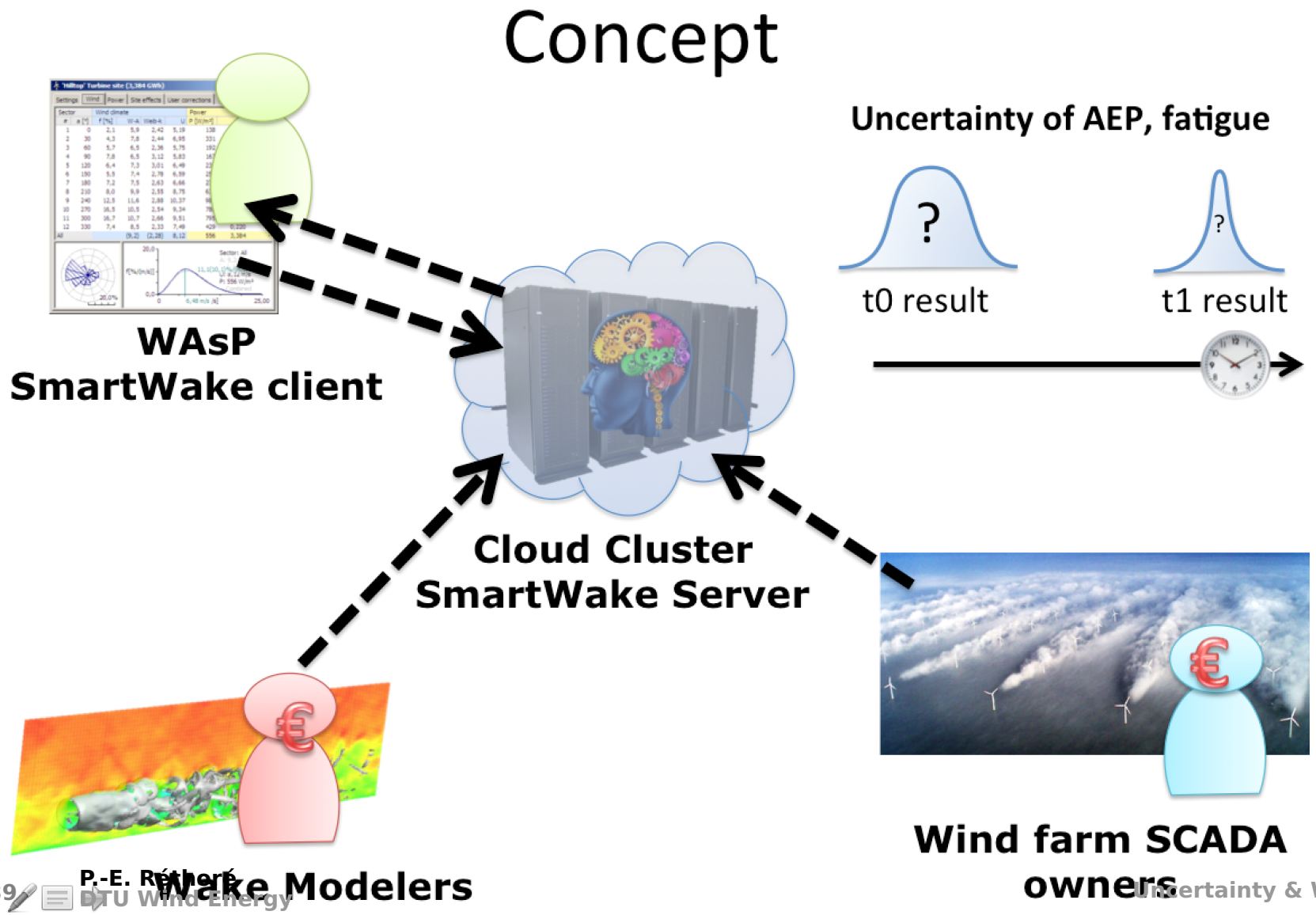


Conclusion

- The N.O. Jensen model, the G.C. Larsen model and Fuga are robust engineering models able to provide accurate predictions using wind direction sectors of 30°
- The discrepancies for narrow wind direction sectors are not caused by a fundamental inaccuracy of the current wake models, but rather by a large wind direction uncertainty included in the dataset
- We need some models and measurements for wind direction uncertainty to move forwards from this stage
- Do not "tune" your wake models to match the ±2.5° measurements!!!

Future work

Wind Farm Flow Model Uncertainty

- The method will be applied to other wake models and datasets
- Sample based uncertainty quantification to be investigated
- Work on estimating the wind direction uncertainty using the wind farm dataset

System Engineering

- Opening FUSED-Wind to the public
- Adding Uncertainty Quantification to FUSED-Wind

Thank you for your attention!

- Work funded by EUDP-WakeBench and EERA-DTOC
- Dataset graciously made available by DONG Energy and Vattenfall.
- Article submitted to wind energy and master thesis available on request

RESEARCH ARTICLE

Evaluation of the wind direction uncertainty and its impact on wake modelling at the Horns Rev offshore wind farm

M. Gaumond[1], P.-E. Réthoré[1], S. Ott[1], A. Peña[1], A. Bechmann[1] and K. S. Hansen[2]

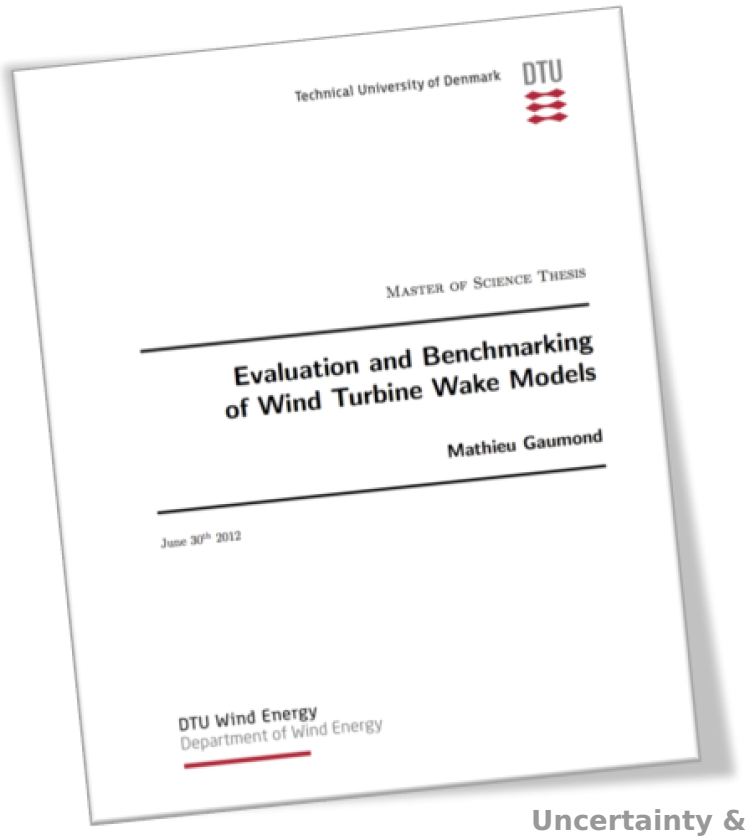
[1]DTU Wind Energy, Risø, Building VEA-118, P.O. Box 49, Frederiksborgvej 399, 4000 Roskilde, Denmark
[2]Department of Mechanical Engineering, Technical University of Denmark, 2800 Kgs Lyngby, Denmark

ABSTRACT

Quantifying accurately wind turbine wakes is a key aspect of wind farm economics in large wind farms. This paper introduces a new post-processing method to address the wind direction uncertainty present in the dataset of the Horns Rev offshore wind farm. This new technique replaces the traditional simulation performed with the 10-minute average wind direction by a weighted average of several simulations covering a wide span of directions. The weights are based on a normal distribution to account for the uncertainty from the yaw misalignment of the reference turbine, the spatial variability of the wind direction inside the wind farm and the variability of the wind direction within the averaging period. The results show that the technique corrects the predictions of the models when the simulations and data are averaged over narrow wind direction sectors. In addition, the agreement of the simulations is improved for the shape of the power deficit in a single wake situation. The robustness of the method is verified using the Jensen model, the Larsen model and Fuga, which are three different engineering wake models. The results indicate that the discrepancies between the traditional numerical simulations and power production data for narrow wind direction sectors are not caused by an inherent inaccuracy of the current wake models, but rather by the large wind direction uncertainty included in the dataset. The technique can potentially improve wind farm control algorithms and layout optimization because both applications require accurate wake predictions for narrow wind direction sectors. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS

wind farms; offshore; wakes; power deficit; wind direction



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MASTER OF SCIENCE THESIS

Evaluation and Benchmarking of Wind Turbine Wake Models

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